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RIKEN BNL Research Center

REFLECTIONS ON MY CONTRIBUTIONS TO PARTICLE PHYSICS AND RECENT EXPERIMENTAL RESULTS FROM RHIC

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Brookhaven National Laboratory,
Upton, New York

January 18, 2002
Dubna, Russia

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Preface to the Series

The RIKEN BNL Research Center (RBRC) was established in April 1997 at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkyusho," (RIKEN) The Institute of Physical and Chemical Research, of Japan. The Center is dedicated to the study of strong interactions, including hard QCD/spin physics, lattice QCD and RHIC (Relativistic Heavy Ion Collider) physics through nurturing of a new generation of young physicists. The Director of RBRC is Professor T. D. Lee.

A Memorandum of Understanding between RIKEN and BNL was signed on April 30, 2002 extending this collaboration and the RIKEN BNL Research Center (RBRC) for another five years.

Since its inception the Center has now matured with both a strong theoretical and experimental group. These consist of Fellows, Postdocs, RBRC Physics/University Fellows and an active group of Consultants/Collaborators. Computing capabilities consist of a 0.6 teraflops parallel processor computer operational since August 1998. It was awarded the Supercomputer 1998 Gordon Bell Prize for price performance. This is expected to be augmented by a ten teraflops QCDOC computer in JFY 2003. The Center also organizes an extensive series of workshops on specific topics in strong interactions with an accompanying series of published proceedings.

Members and participants of RBRC on occasion will develop articles in the nature of a status report, a general review, and/or an overview of special events, such as this one.

N. P. Samios

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Reflections on My Contributions to Particle Physics and Recent Experimental Results from RHIC

N. P. Samios
January 18, 2002
Dubna, Russia

It is a pleasure to be here in Dubna to receive the 2001 Bruno Pontecorvo Prize in particle physics. My previous visit to this laboratory was in 1964, attending the International Conference on High Energy Physics. It was at that time that I had the pleasure of briefly interacting with Dr. Pontecorvo and with his son who is here today and providing the simultaneous translation of my talk. Bruno Pontecorvo is world renowned for his seminal contribution to particle/nuclear physics. In particular his extensive insights into the realm of neutrino physics have been especially noteworthy.

My talk today will be composed of two parts. The first part will consist of a summary of some of my experimental contributions over the years. It will not be exhaustive but will highlight the findings that had relevance to the progress of our understanding of particle physics as it has evolved over the years. This section will be divided into three periods: Early, Intermediate and Late, with an in depth discussion of a few of the more significant results. The second part will consist of a discussion of the recently completed Relativistic Heavy Ion Collider (RHIC) machine at Brookhaven National Laboratory (BNL). This will encompass the parameters of the accelerator and some of the interesting and exciting early experimental results emanating from this machine.

The pertinent experimental findings from my early period of experimental work are tabulated in Figure I. In addition to listing these discoveries, their physics relevance is also noted. The discovery of the Σ° hyperon[1] and the determination of the spins of the Λ° and Σ^- [2] were critical in establishing the baryon $J^P = 1/2+$ multiplet. The measurement of the parity of the π° meson[3] was a tour-de-force, one million bubble chamber pictures. The experimental results are displayed in Figure 2. The discriminating factor in determining the parity of the π^o is the angle between the planes of the two Dalitz pairs from the π^o decay. What is displayed are the experimental results after accumulating 103 events and 206 such events. The correlation[3] expected for pseudoscalar parity was -.47 and for scalar +.47. The determination of α = -.75 $\pm$ .42 with half of the events and α = - .41 $\pm$ .24 with the full sample clearly demonstrated that the parity was odd. The interesting historical observation is that the significance of both samples was the same due to the fact that the early data gave a favorable fluctuation for the ultimate result. The search for parity non-conservation in hyperon was the subject matter of my thesis at Columbia University. This possibility was pointed out by Lee and Yang in their famous paper[4] and the first evidence for such a violation in weak interactions was performed by Madame Wu [5] and collaborators in Co^{60} decay. As shown in Figure 3, the signature for such an effect is the observation of an up down asymmetry in Λ° decays produced by pion-nucleon interactions in association with a K^o. The first attempt at such a measurement with 22 Λ° 's [6] yielded an up down ratio of 14/8; the second which was my thesis with 41 Λ° 's gave a value of 24/17; and the definitive determination with 263 events[7] yielded an asymmetry of 184/79 leading to a parity violation of .40 $\pm$ .11, roughly a four standard deviation effect. This clearly demonstrates the importance of accumulation of sufficient data in order to establish an important effect. The final important contribution of this early period involved the observation of the beta decay of the pion. Results on the process had been determined which were in conflict with the rate expected on the basis of the V-A nature of the weak interactions. Our observation of 6 such decays out of a sample of 65,000[8] yielding a rate of $\sim 10^{-4}$ was much larger than the previously upper limits of 10^{-5} and in agreement with the vector theory of weak interactions. This experimental work involved the efforts of many people, the more prominent being Dr. J. Steinberger, Dr. M. Schwartz, and Dr. J. Leitner.

The intermediate period of my experimental activity was mainly preoccupied with the search and discovery of important mesons and baryons. The more important of these endeavors are listed in Figure 4 again with comments on the relevance of each finding. The discovery of the Φ meson[8,9] and $\Xi(1530)$ hyperon[8] were of major importance and were also presented at the 1962 Rochester Conference held at CERN. The data for the Φ is shown in Figure 5 and that for the $\Xi(1530)$ in Figure 6. The uncovering of the Φ was a delight in that one not only had a mass bump but a $K^o{}_S K^o{}_L$ correlation that clearly indicated a new particle with a spin parity assignment of one minus. This particle completed the nonet composed of the ρ, ω, K* and now Φ and the masses satisfied the Gell-Mann-Okubo mass formula. I note in passing that this early data also correctly determined the 3π decay of the Φ of 15% which later was of interest with regard to the decay dynamics a la Zweig allowed and suppressed diagrams. The reporting of the discovery of the Ξ(1530 at CERN and subsequently in Physical Review Letters was indeed timely, for Gell-Mann seized on it to further his SU(3) formulation for explaining the spectroscopy of particles. It was shortly thereafter that we determined the spin of the $Y_1^*(1385)$ to be 3/2[11]. This was quite important since previous evidence was ambiguous, in fact favoring spin one half, and this value of 3/2 gave credence to the possibility of a decimet of spin 3/2 composed of the Δ, $Y_1^*(1385)$, Ξ(1530 and a predicted Ω^-, a singlet of strangeness minus 3. From our previous experience of utilizing K^-p interactions to search for new resonances, it was natural to continue such explorations with high energy kaon beams, 5 GeV, and larger targets, 1,000 liters of liquid hydrogen versus 10 liters. This was done and the event shown in Figure 7 was found, a beautiful example of the production and decay of an Ω^- hyperon[12]. The reaction is displayed in Figure 8 where the elaborate sequence in particle production and decay is noted, all particles visible in the hydrogen bubble chamber. The conversion of both gamma rays from the π^0 decay was most extraordinary, the probability for such an occurrence being less than 1%. This discovery, albeit originally one event, gave great credence to the SU(3) symmetry. This was quickly followed within a year by the discovery of the $\eta^1(960)$[13] and f^1 (1525) [14] mesons. These two particles were singlets that completed the J^P 0^- and 2^+ nonents. For completeness I include in the discussion the search for a strangeness plus 2 meson[15] whose negative results indicated that higher order multiplets such as 27 and $\overline{10}$ did not exist and that the known particles were accommodated in smaller multiplets, namely 8's and 10's. The work encompassing this intermediate period had a major effect on the evolution of the understanding of the spectroscopy of particles, the advent of quarks and eventually the standard model of QCD. Again these important experimental findings resulted from the fine work of many individuals, the more prominent being Dr. J. Leitner and Dr. R. B. Palmer.

The later phase was concerned with neutrinos; the study of the dynamics of neutrino interactions, as well as the use of neutrinos as a producer of new particles and phenomena. Figure 9 contains a list of the more important findings. This includes an early measurement of the total and quasi-elastic neutrino cross section at energies between 0.5 GeV and 5 GeV.[16] The linear rise of the total cross section with energy was observed as well as a measurement of the axial vector form factor. This was followed by the discovery of baryon charm.[17] The particular neutrino reaction is shown in Figure 10 and the event in Figure 11. The beauty of this event is that nearly all the particles identified themselves either by decaying, scattering or emitting a delta ray. Furthermore the kinematics are such that this one event provided the basis for the discovery of two particles, the Σ_c^{++} and Λ_c^{+}. In fact the nomenclature for naming the charm baryon particles was first introduced in this paper, namely using the generic name for particles and adding the subscript c for each interchange with an S quark. He who finds the particle, names it.

The more difficult experiment involving neutrino electron elastic scattering followed. The expected rate for such events was one in ten thousand of the rate for neutrino hadron scattering, quite an undertaking. Twenty such events were found[18] and a picture of one such 20 GeV electron is shown in Figure 12 clearly identified by the magnificent shower. The extracted value from these data for the sine squared of the Weinberg angle was 0.22 $\pm$ .06, amazingly close to the presently accepted value of 0.23.

The dynamics of charm production was explored by studying high energy neutrino interactions, in particular di-lepton production. The observation of such opposite sign leptons[19], mu minus and positive electrons, accompanied by strange particles was a clear signature for charm production. Indeed the measurement of the cross section, angular distributions and decay modes all contributed to the understanding of the influence of this fourth charm quark. I conclude this section by noting of the early efforts in the search for neutrino oscillations in 1981.[20] The limits obtained are shown in Figure 13 where the difference in the neutrino mass squares are plotted as a function of the mixing angle. The limits obtained at this time were of the order of one electron volt squared. We now know that such oscillations exist, but at values ten thousand times smaller. This work was done in collaboration with many people, the most senior being Dr. C. Baltay and Dr. R. B. Palmer.

A glimpse of some of my contributions to particle physics can be ascertained from Figure 14. Here I have noted the particle members of meson and baryon multiplets. I have put circles around these particles in which I participated in their discovery and arrows under those whose properties I have helped delineate. It was a challenge as well as a pleasure to have been an active contributor to the field at such an exciting time. Of course all these myriad of particles have been replaced by a few quarks and their interactions described by Quantum Chromodynamics.

Early:

Discovery of Σ^o	Σ^+ Σ^- Σ^o Triplet Baryon Multiplet
Parity of π^o	π^+ π^- π^o Triplet Meson Octet
Λ^o, Σ^- Spin 1/2	Baryon Multiplet
Parity non-conservation In Λ^o decays	Parity violation in Hyperon Decays
Pion β decay	V-A nature of Weak interactions

Fig. 1

$\pi^0 \to e^- e^+ \; e^- e^+$

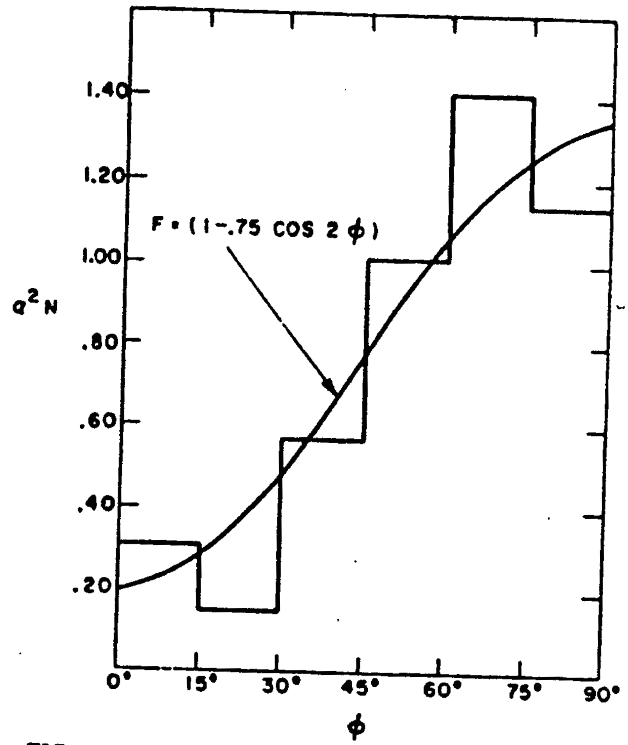

FIG. 2. Plot of weighted frequency distribution of angle between planes of polarization.

103 events.

$\alpha_{exp} = -.75 \pm .42$

$\alpha_{th}^{PS} \; -.47$

$\alpha_{th}^{S} \; +.47$

206 events.

$\alpha_{exp} = -.41 \pm .24$

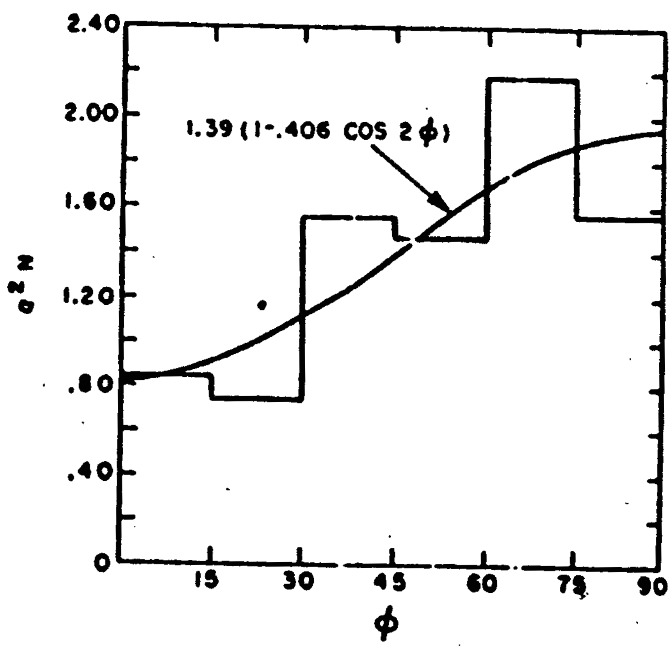

FIG. 9. Plot of the weighted frequency distribution of the angle between planes of polarization.

Fig. 2

Parity non-Conservation in Hyperon Decay

$$\pi^- p \to \Lambda^0 K^0$$

$$\Lambda^0 \to p\,\pi^-$$

pseudoscalar

$$(\vec{P}_{\pi^-} \times \vec{P}_{\Lambda^0}) \cdot \vec{P}_p \qquad \text{up/down}$$

Budde et al 22 Λ^0's 14/8

Samios (thesis) 41 events 24/17 ±.30

Steinberger et al 263 events 184/79

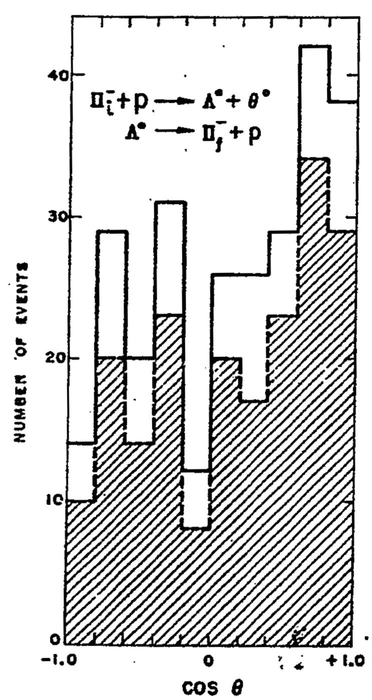

FIG. 1. Distribution in cosθ for process (1). The shaded area represents events for production angles in the center-of-mass

$$\alpha_\Lambda \bar{P}_\Lambda = .40 \pm .11$$

Fig. 3

Intermediate:

Discovery of

• Φ meson	1^- nonet
• Ξ (1530) hyperon	$3/2^+$ decimet
Spin of Y_1^* (1385) 3/2	$3/2^+$ decimet
• Discovery of Ω^- hyperon	SU(3)
Discovery of η^1(960) meson	o^- nonet
f^1(1525) meson	2^+ nonet
Non-Existence of S = +2 Meson	Quarks

Fig. 4

$\phi(1020)$ BNL (Connolly et al.)

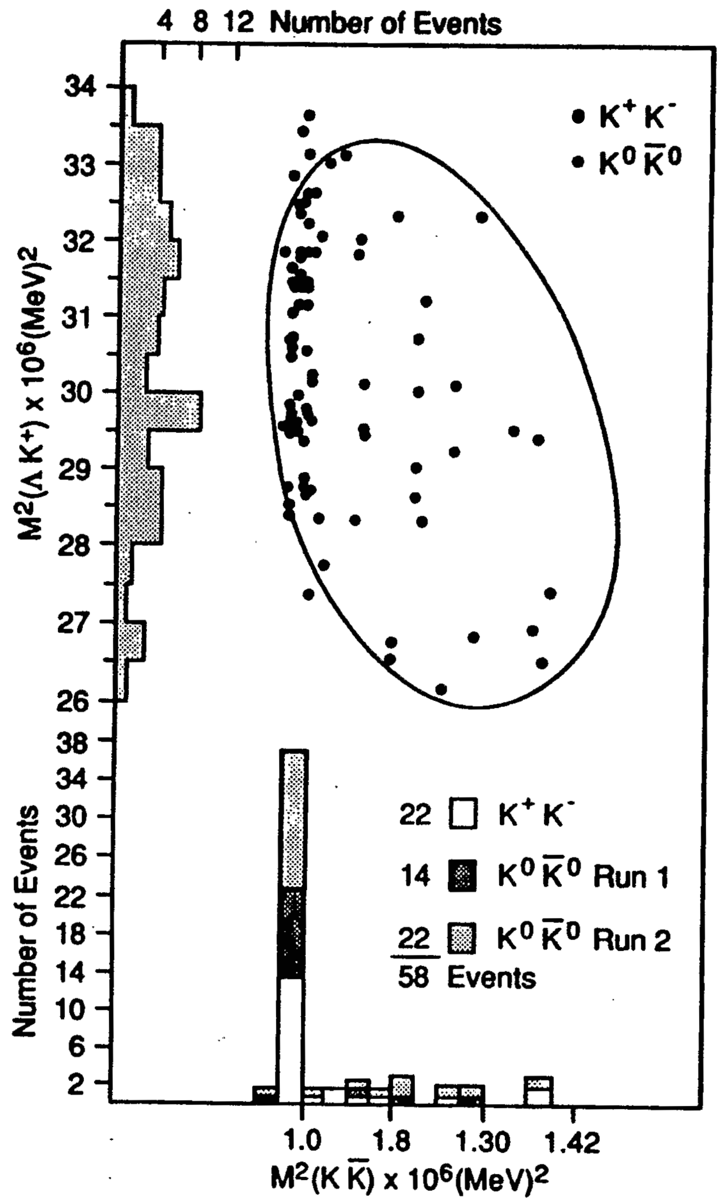

Fig. 4

$K^-p \rightarrow \Lambda^0 K^+ K^-$

$\Lambda^0 K^0 \bar{K}^0 \qquad K_S K_L$

Samios 4a 3/93 judy

Fig. 5

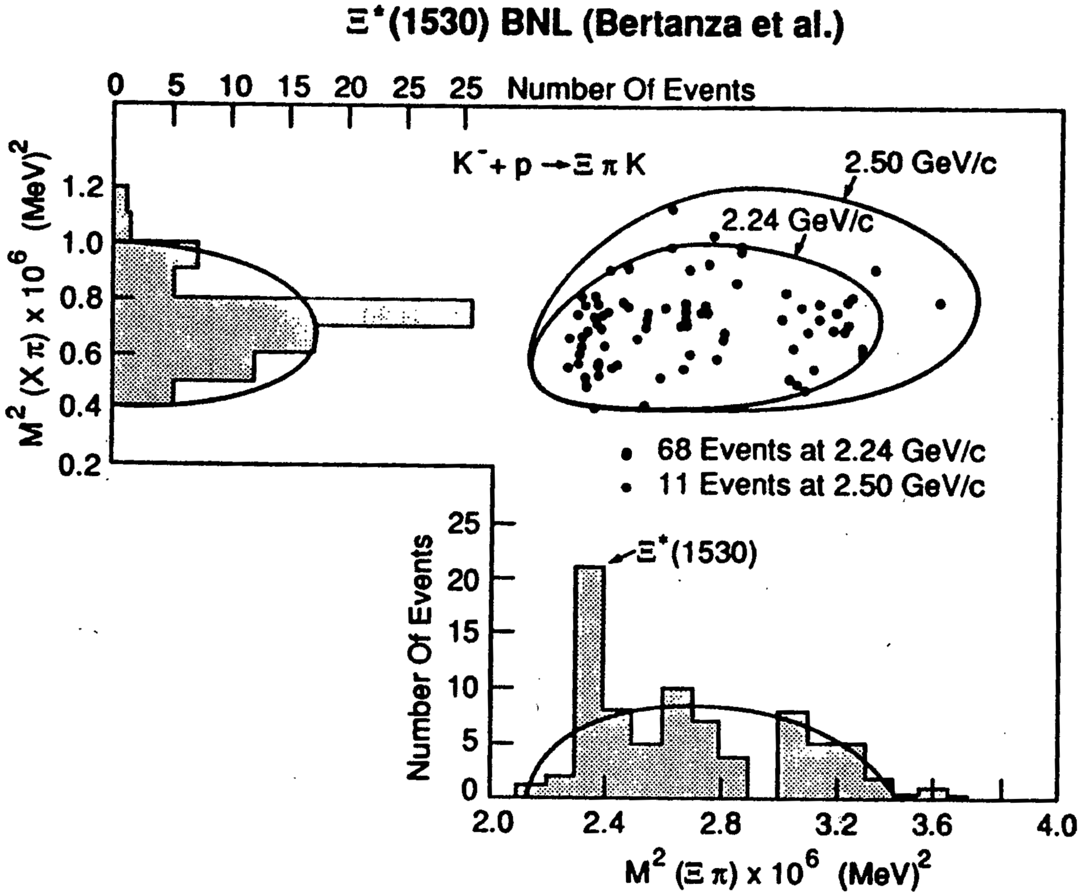

Fig. 1. The Dalitz plot for the channel $\Xi\, \pi\, K$ projected on the $M^2(K\,\pi)$ and the $M^2(\Xi\,\pi)$ axes. The solid curves on the projections are the invariant phase-space curves normalized to the total number of events.

$$K^- p \rightarrow \Omega^- K^+ K^0$$

$$\hookrightarrow \Xi^0 \pi^-$$

$$\hookrightarrow \Lambda^0 \pi^0$$

$$\pi^0 \hookrightarrow \gamma + \gamma$$

$$\gamma \hookrightarrow e^+ e^-$$

$$\gamma \hookrightarrow e^+ e^-$$

$$\Lambda^0 \hookrightarrow p \pi^-$$

Fig. 7

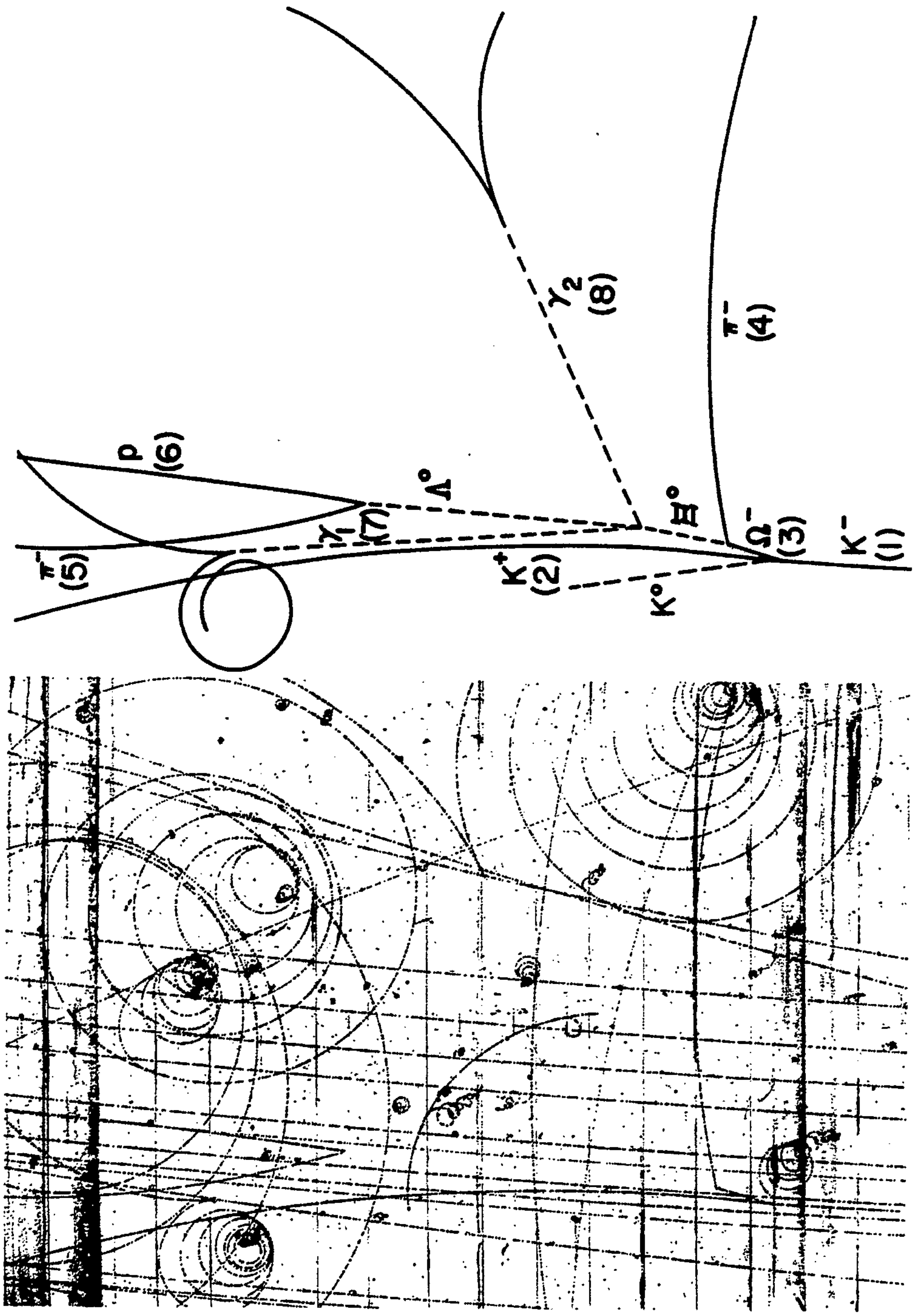

Fig. 8

Later:

Measurement of Neutrino Cross Section Total and quasi-elastic	Scaling and Axial vector Form factor
Discovery of Baryon Charm Σ_c^{++} and Λ_c^{+}	Fourth Quark
Neutrino-electron Elastic Scattering	$\sin^2\theta_w = .22 \pm .06$
Di-lepton Production in Neutrino Interaction	Dynamics of Charm Production
Experimental Limits on Neutrino Oscillations	Neutrino Mixing

Fig. 9

$$\nu p \rightarrow \mu^- \Sigma_c^{++}$$

$$\Sigma_c^{++} \longrightarrow \Lambda_c^+ \pi^+$$

$$\hookrightarrow \mu^+ \nu$$

$$\hookrightarrow e^+ \nu \bar{\nu}$$

$$\Lambda_c^+ \longrightarrow \Lambda^0 \pi^+ \pi^+ \pi^-$$

$$\hookrightarrow \pi^+ e^- \rightarrow \pi^+ e^-$$

$$\hookrightarrow \pi^+ p \rightarrow \pi^+ p$$

$$\hookrightarrow p \pi^-$$

Fig. 10

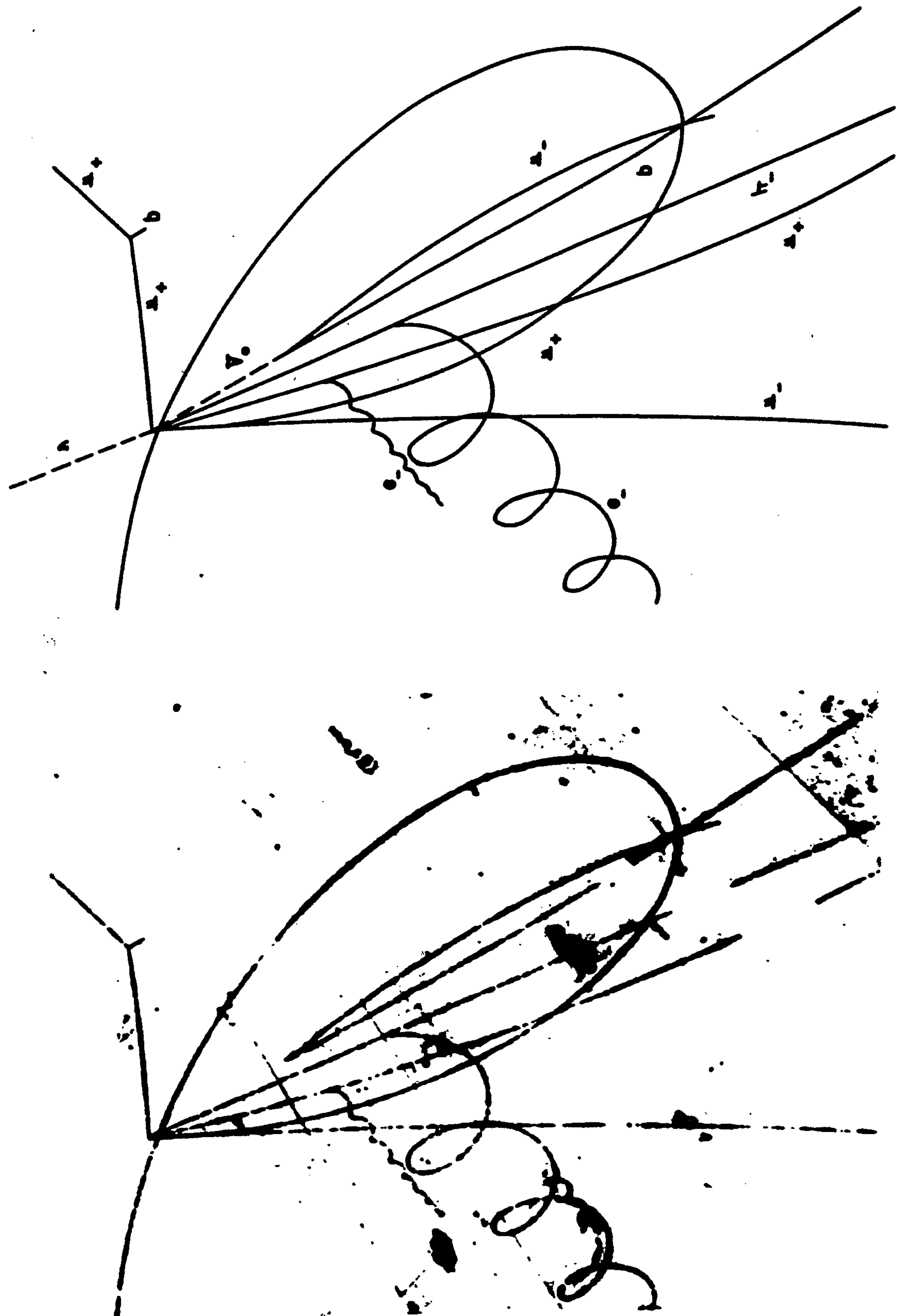

Fig. 11

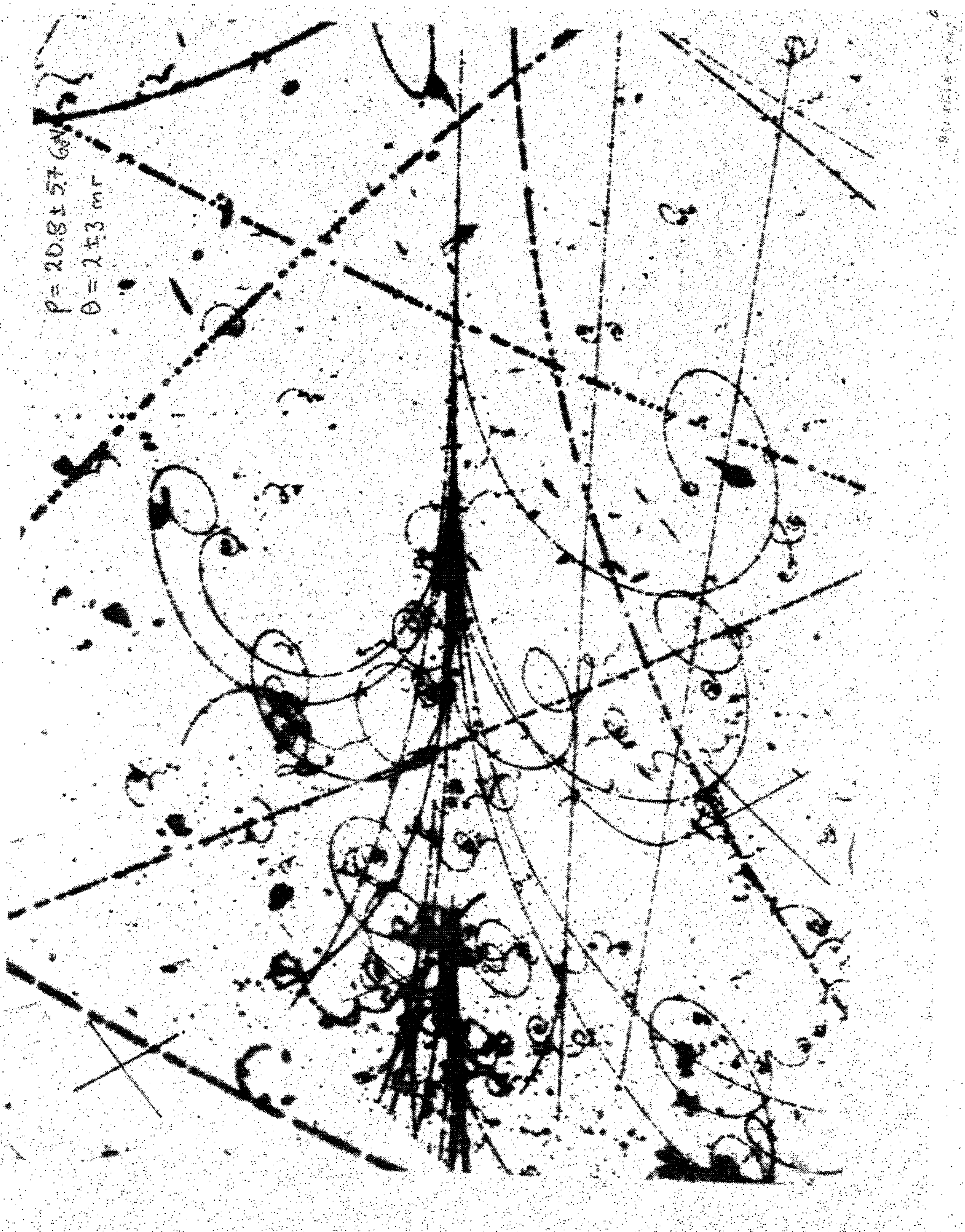

Fig. 12

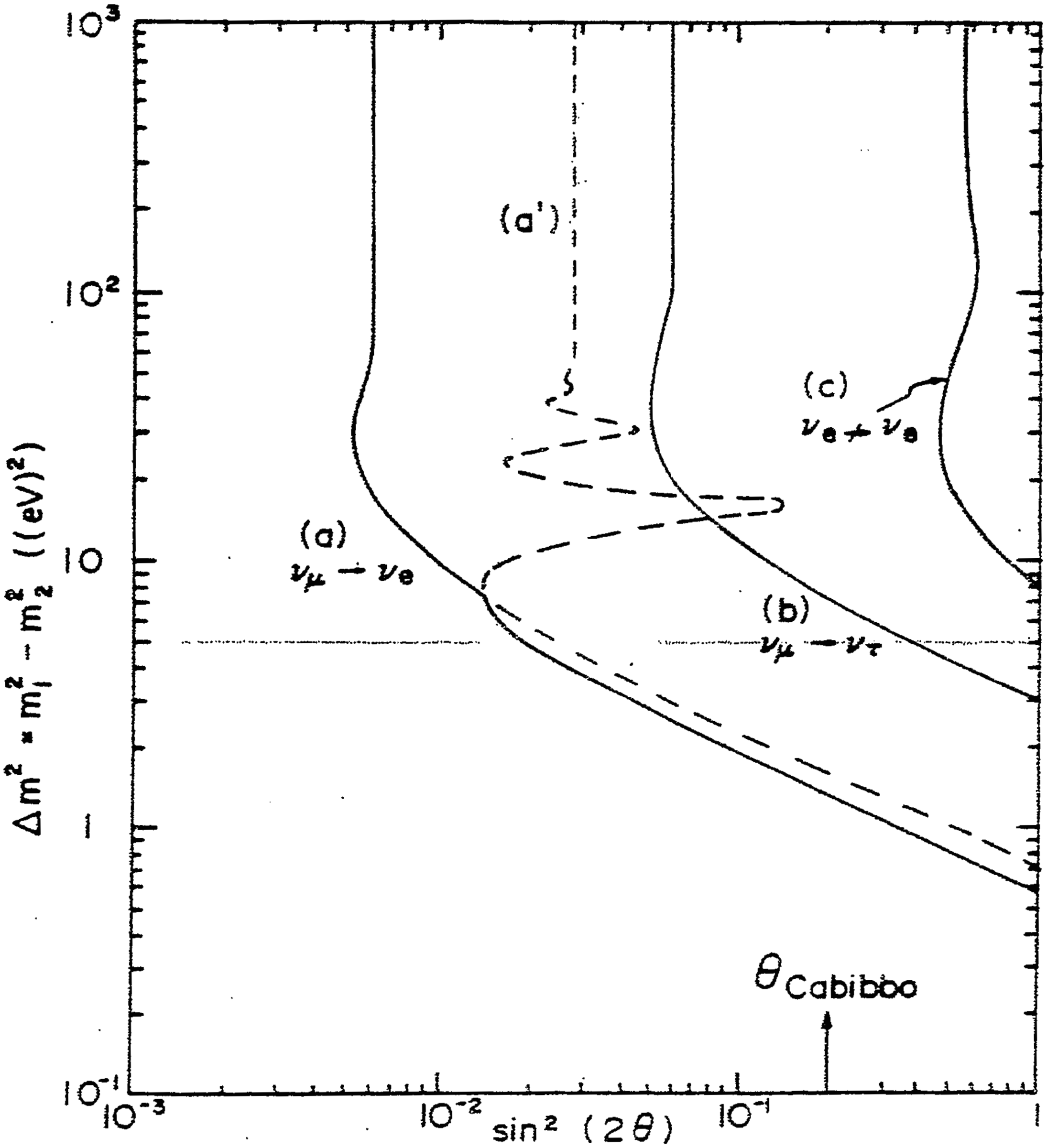

FIG. 1. Limits on the neutrino oscillation parameters $\sin^2(2\theta)$ vs Δm^2. Curves a, b, and c display the 90% confidence level limits for the transitions $\nu_\mu \to \nu_e$, $\nu_\mu \to \nu_\tau$, and $\nu_e \to \nu_{\sim e}$, respectively, obtained by the flux subtraction method. Curve a' displays the 90% confidence level limit for the transition $\nu_\mu \to \nu_e$, obtained from the low-energy data. The 90% confidence level limit obtained for the $\nu_\mu \to \nu_\tau$ transition by the kinematical method is also given by curve b. For each transition, the region to the right of the solid line is excluded by this experiment. Also shown is the Cabibbo angle.

Fig. 13

Particles

Mesons

J^P				
0^-	$\pi^{\pm}\pi^{\circ}$ ↑	K	η	η'
1^-	ρ	K^*	ω	Φ
2^+	A_2	K^{**}	f°	f'

Baryons

$1/2^+$	$\Sigma^{\pm}$ ↑ Σ°	Ξ ↑	Λ ↑	
$3/2^+$	Δ	Y_1^* ↑	Ξ^*	Ω^-
$1/2^+$	Λ_c^+	Σ_c^{++}		

○ Discovery

↑ Properties

In the second part of my talk today I will briefly discuss the progress and prospects of the Relativistic Heavy Ion Collider (RHIC) at BNL. This accelerator, which is now operational, was designed to accelerate all species of ion beams, at many energies. The top energies for heavy ion is 100 GeV/Amu per beam and 250 GeV for protons. The physics to be explored is that of nuclear matter under conditions of high temperature, 200 MeV or more, and high energy density, 5-10 times that of a normal nucleus. As such we expect to enter new regimes of nuclear matter, namely the quark gluon plasma and color glass condensates. The history of the RHIC project is outlined in Figure 15; the RHIC facility in Figure 16; and the acceleration scenarios for Au Beams in Figure 17. A view of the RHIC tunnel and the two concentric rings of superconducting magnets are shown in Figure 18. This RHIC accelerator complex has attained its peak design parameters in energy and luminosity and was completed on time and on budget. This feat was accomplished with Dr. S. Ozaki as project head with the able assistance of his two principal deputies, Dr. M. Harrison for the accelerator and Dr. T. Ludlam for detectors and the very able staff of the RHIC project. There are four detectors at RHIC involving a total of 1,000 individuals from 100 institutions worldwide. There are the large STAR and PHENIX and the small PHOBOS and BRAHMS detectors illustrated in Figure 19. All four detectors have already produced some interesting and exciting results, and I will now briefly comment on a few of these findings.

The first has to do with the charged particle multiplicity. In at RHIC each effective central nucleon-nucleon collision produces 40%

more particles than that in p $\bar{p}$ collisions. This is shown in Figure 20 where multiplicity data for both central AA and p $\bar{p}$ collisions are plotted as a function of center of mass energy. One sees a difference with a clear excess of charged particles produced by the gold-gold collisions. A second interesting feature observed was that of the p $\bar{p}$ ratio which is indicative of how close to a vacuum state (no net quarks) one is achieving in the central rapidity region in RHIC. A measurement of this ratio as a function of rapidity and center of mass energy is shown in Figure 21. One notes values of (.7-.8) for the p $\bar{p}$ ratio compared with zero at AGS energies and 0.2 at CERN fixed target lead-lead collisions. One is clearly close to a zero quark-antiquark free state.

It is possible to measure the shape of the interaction volume by means of particle interferometry, namely two like particle HBT measurements. This has been done using like sign pions where one determines the correlation function for identical bosons. Such an analysis and results are displayed in Figures 22 and 23. The peaking at low q is observable leading to values of R_{Out} and R_{Side} of ≈ 5.5 fermi's and R_{Long} of 7 fermi's. The amazing finding is that these values are roughly the same as that at the AGS and SPS, no change in going from 5 GeV to 20 GeV to 200 GeV energies. Another method to derive a shape is via elliptic flow, which is the second Fourier harmonic coefficient of the azimuthal distribution of particles with respect to the reaction plane. This can be examined versus the P_t and the centrality of the collisions. The data are shown in Figure 24 and compared with hydodynamic predictions, which don't agree.

The interesting point is that the relatively large value of v_2, which is indicative of an azimuthal asymmetry, indicates an elliptic shape for the peripheral collisions and even a small but finite value for central collisions.

The final new interesting result concerns the P_t distribution for pions from peripheral and central collisions. The data for charged and neutral pions is shown in Figure 25. One sees that the pions from peripheral collisions agree with that expected from scaling from nucleon-nucleon collisions. On the other hand both signs of pions, neutral and charged, in central collisions are less than the expected scaled values. This is totally unexpected since enhancements have previously been seen in the P_t distribution of pion yields of nucleus-nucleus collisions and proton-nucleus collisions. This is a suppression. There can be several explanations for this effect among which is the increased energy loss of particles as they transverse a quark-gluon plasma; or the effects of the gluon saturation of a color glass condensate on such emitted pions. Future experimentation is expected to clarify this situation.

I have attempted in this brief presentation to give you a flavor of both some of my travails in the field of particle physics as well as the exciting and promising prospects of RHIC physics. Although there were indeed exciting times in the past, I believe we can expect even further surprises in the future. I've already noted such possibilities at RHIC. In the realm of particle physics the standard model seems to fit nearly all the experimental data, however there are indications both theoretical and experimental that this is not the whole story. A theory recent measurements of ε'/ε of the kaon and g-2 of the muon, both deviating from expectations, may be a first sign that something more is needed. And of course the recent solar and atmospheric neutrino observations clearly indicate that the neutrinos have mass and this is also indicative of new physics. It is a pleasure to note that a previous recipient of the Pontecorvo Prize, Dr. Ray Davis of BNL, was a pioneer in this field of solar neutrino physics. And it is also proper to acknowledge that Dr. Pontecorvo was one of the early proponents of the concept of neutrino mixing. I end on this pleasant note.

RHIC

The RHIC Project

RHIC is

- Flagship Nuclear Physics Research Facility of the US-DOE
- A Two-Ring, High Energy Hadron Collider for Heavy Ion Collisions
- Use Existing AGS Complex as the Injector

Total Project Cost (including R&D and Pre-Operations) =$ 616.5M
Completed on Schedule and within Budget

RHIC Project History:

1983: The Project Conceived as Part of US NSAC Long Range Plan
1986: CDR Submitted to DOE & Collider R&D Began
1989: Detector R&D Initiated
1991: The Construction Began
1992-5: Four Detectors Approved, One-by-One
1999: Construction Completed and Functionality Verified
2000: Relativistic Heavy Ion Collision Physics Program Began

17 Years after the Idea was Conceived

The RHIC Facility

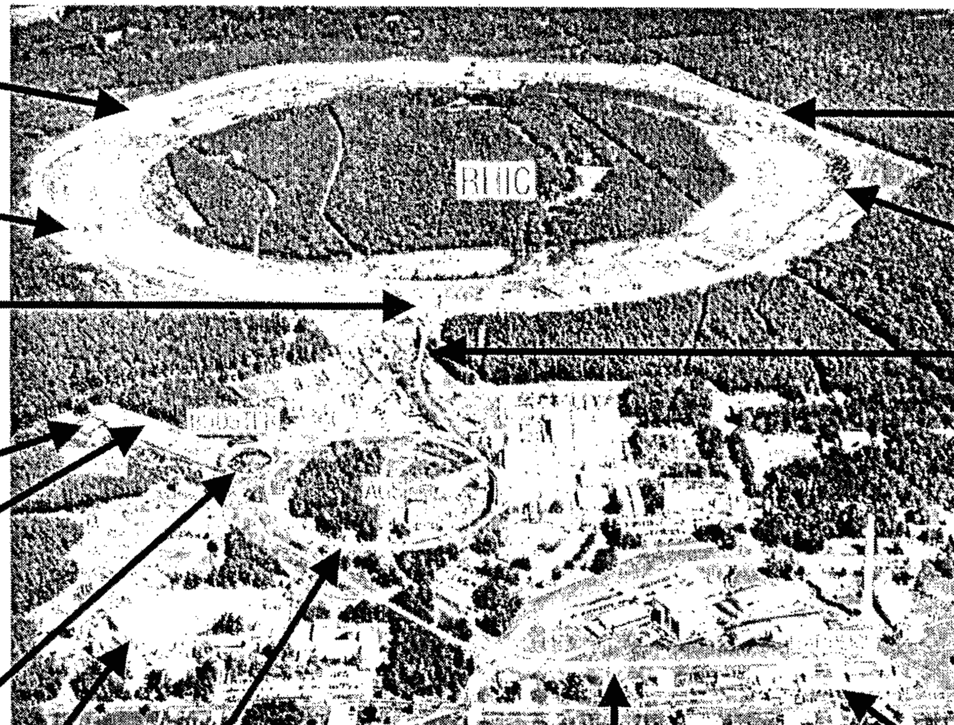

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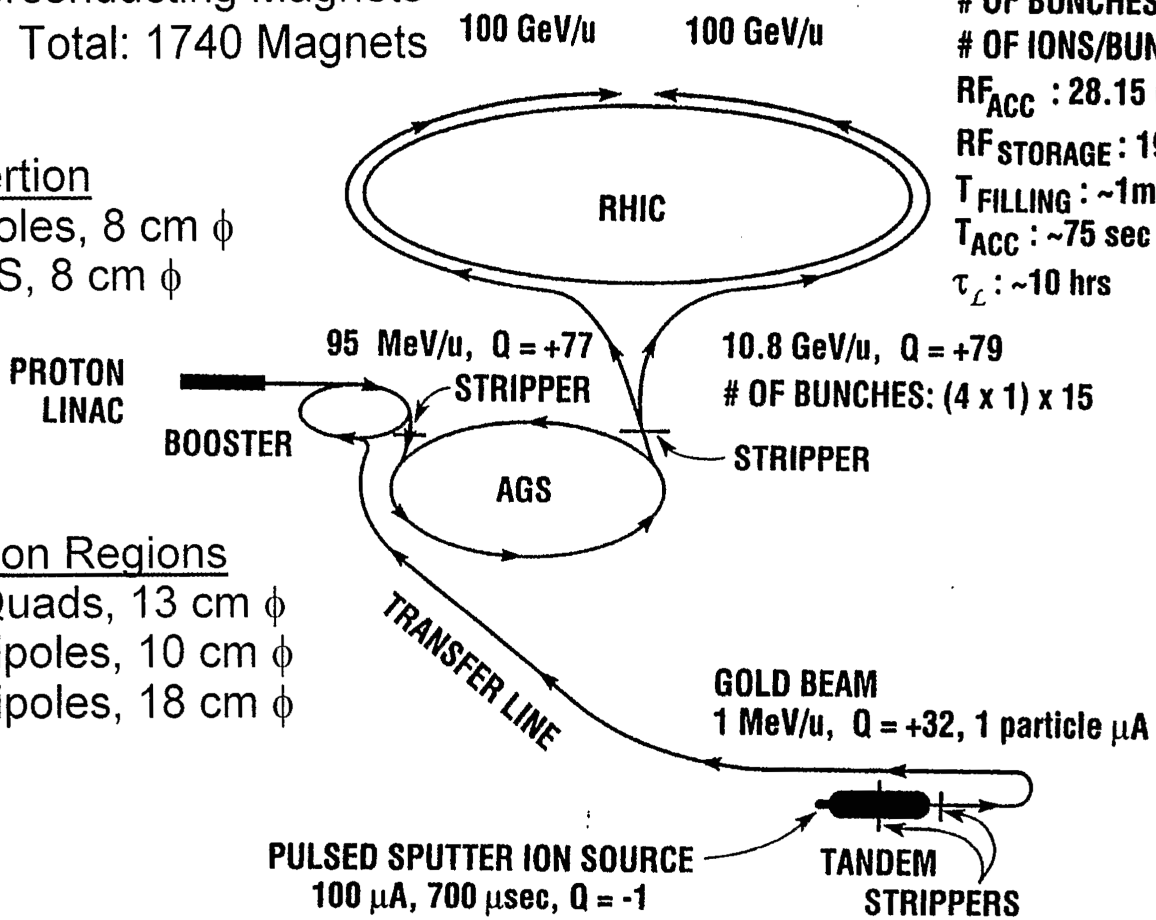
Fig. 16

RHIC Acceleration Scenario for Au Beams

All Superconducting Magnets
Total: 1740 Magnets

Arc/Insertion
360 Dipoles, 8 cm ϕ
420 CQS, 8 cm ϕ

Interaction Regions
96 FF Quads, 13 cm ϕ
24 IR Dipoles, 10 cm ϕ
12 IR Dipoles, 18 cm ϕ



OF BUNCHES: 60
OF IONS/BUNCH: 1×10^9
RF_{ACC} : 28.15 MHz, 0.6 MV
$RF_{STORAGE}$: 197 MHz, 6 MV
$T_{FILLING}$: ~1min
T_{ACC} : ~75 sec
$\tau_{\mathcal{L}}$: ~10 hrs

Fig. 17

RHIC

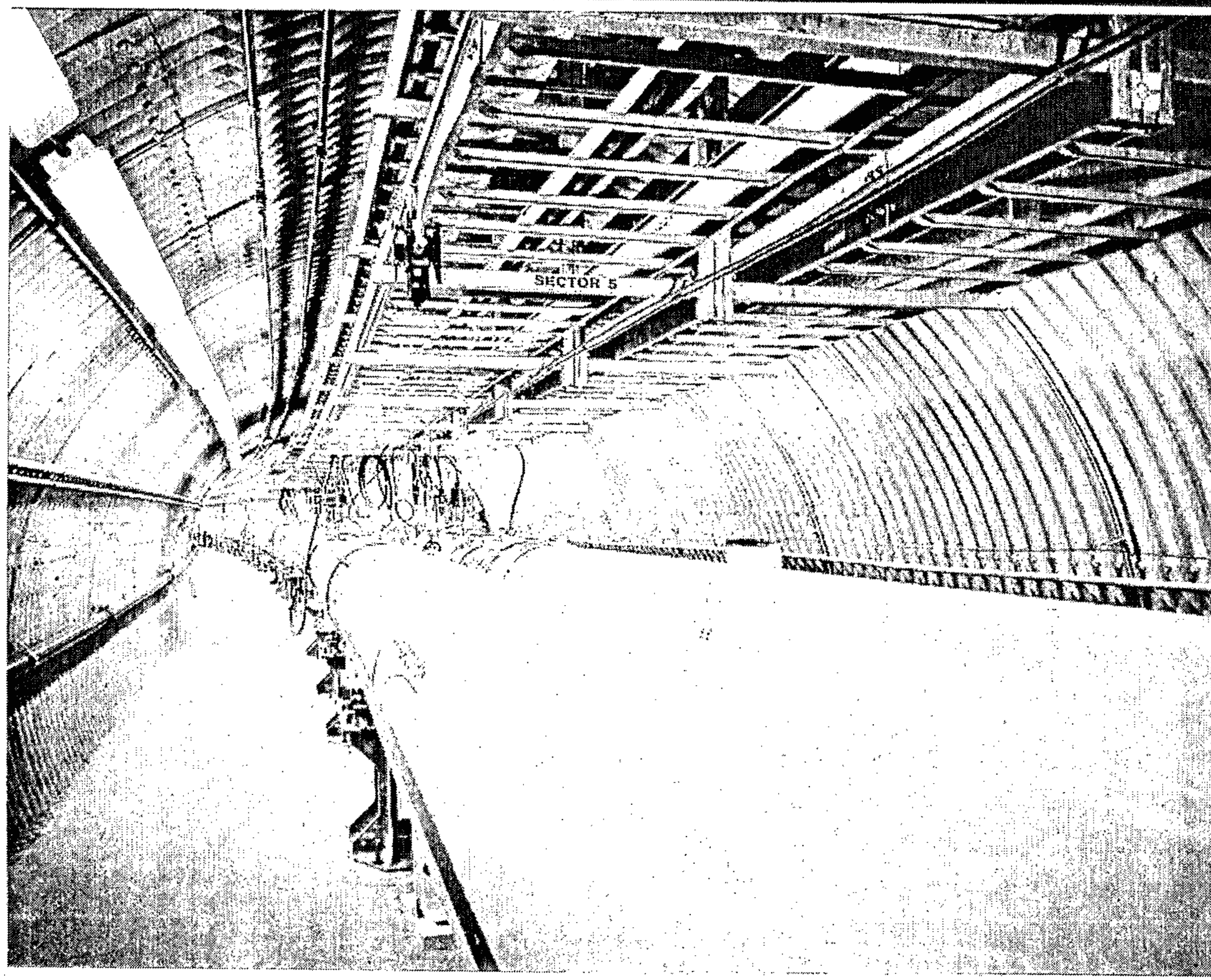


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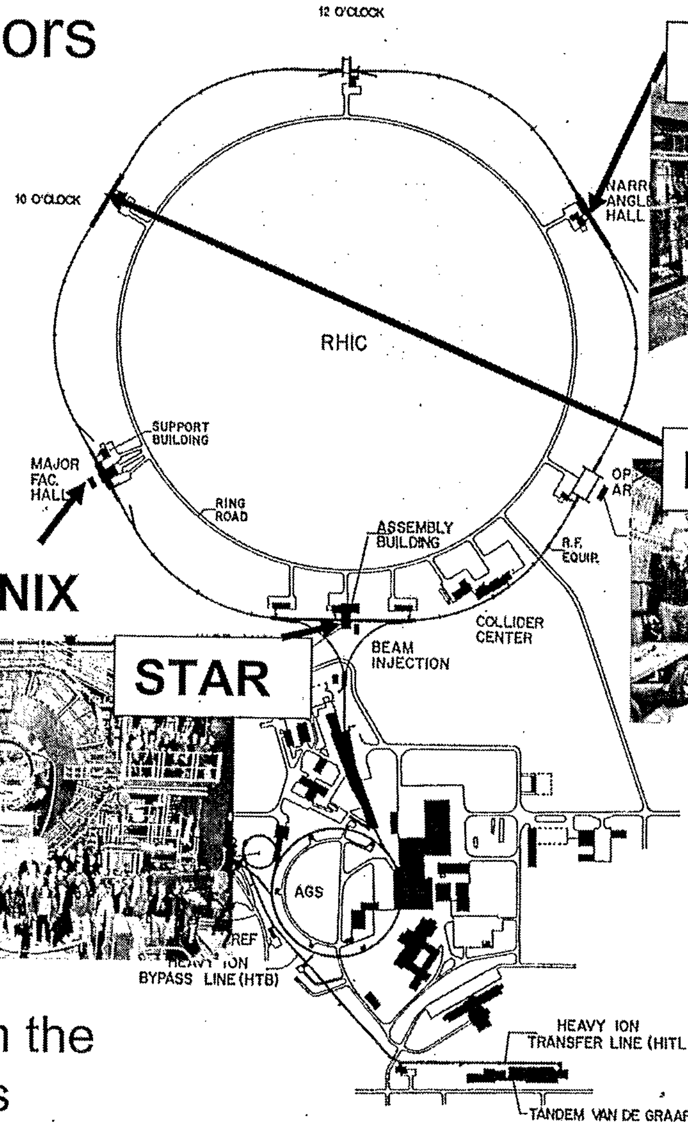
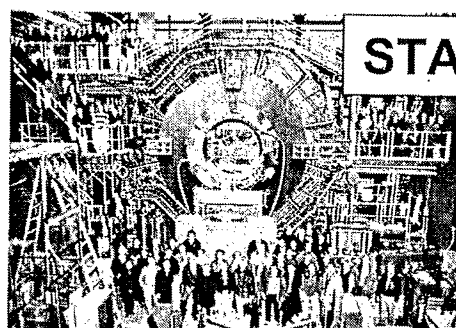
Fig. 18

RHIC Detectors





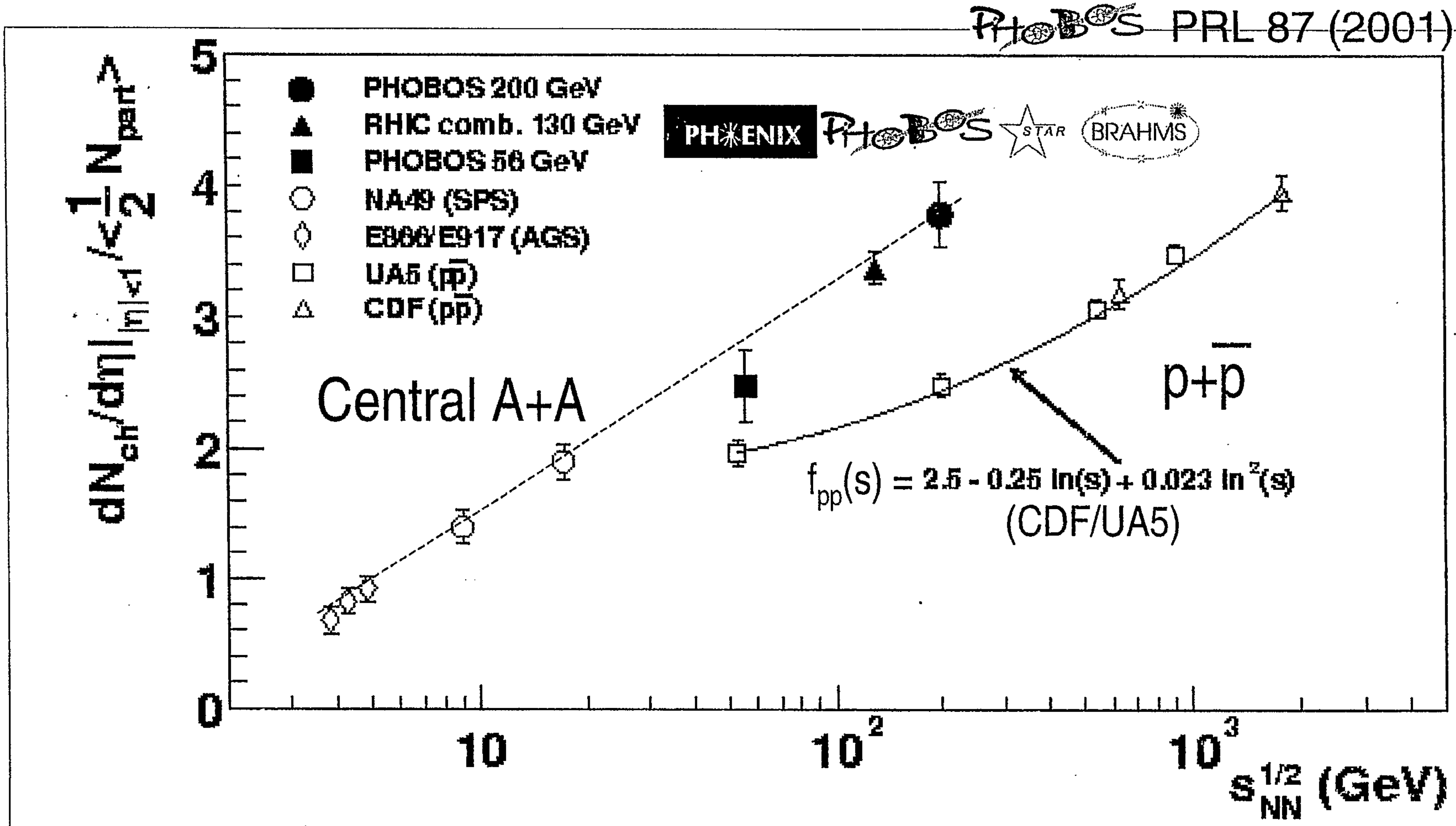
2 Large Detectors
- STAR
- PHENIX

2 "Small" Detectors
- PHOBOS
- BRAHMS

All Participated Successfully in the FY 2000 & 2001 Physics Runs

Fig. 19

AA normalized to equivalent NN

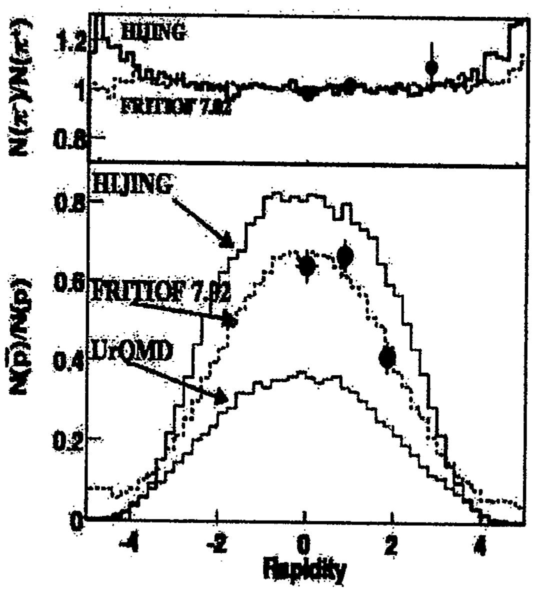


- Each effective nucleon-nucleon collision in central collisions of nuclei produces 40% more particles than pp!

Fig. 20

Peter Steinberg

BROOKHAVEN NATIONAL LABORATORY



130 GeV Au-Au

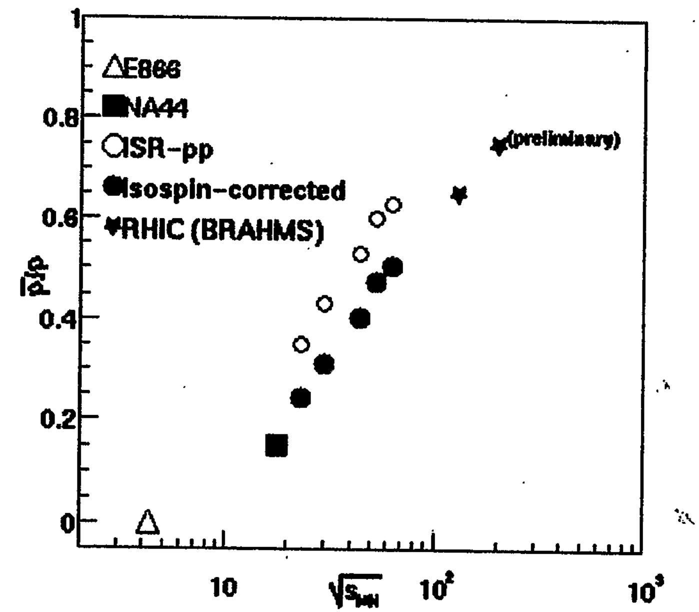


Fig. 21

Two-Particle Interferometry (HBT)

- Correlation function for identical bosons:
- $C(p_1, p_2) = P(p_1, p_2) / (P(p_1) P(p_2)) = 1 + |\rho(q)|^2$
- ρ : Fourier transform of the density distribution
- $q = p_1 - p_2$
- Usual: Bertsch-Pratt parameterization
  $C(q_{out}, q_{side}, q_{long}) = 1 + \lambda \exp(\Sigma q_i^2 R_i^2)$
- <u>STAR</u>:
- 1d projections of 3d Bertsch-Pratt
- 12% most central out of 170k events
- Coulomb corrected
- $|y| < 1$, $0.125 < p_t < 0.225$

$$\lambda = 0.50 \pm 0.01 \pm 0.03$$
$$R_{Out} = (5.86 \pm 0.11 \pm 0.23)\, fm$$
$$R_{Side} = (5.47 \pm 0.09 \pm 0.16)\, fm$$
$$R_{Long} = (7.07 \pm 0.12 \pm 0.21)\, fm$$

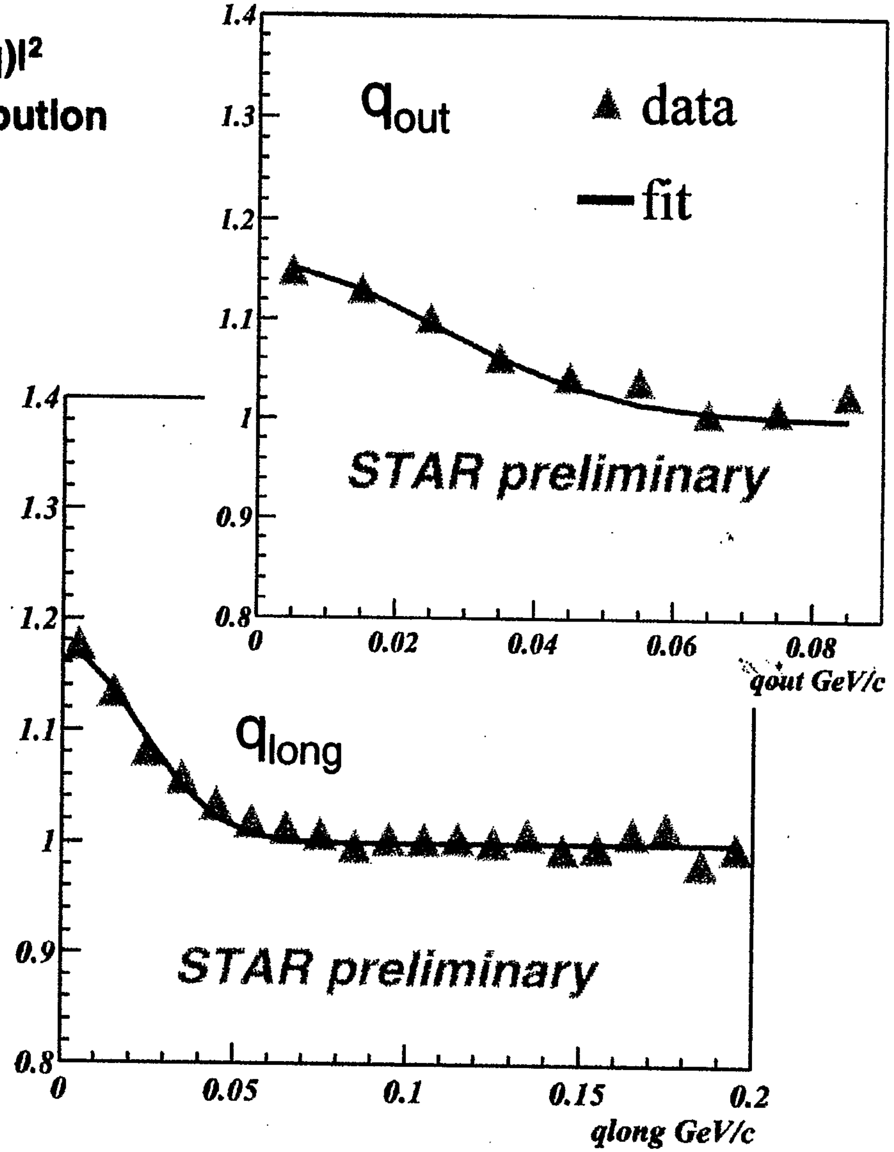


Fig. 22

STAR

Pion HBT Excitation Function

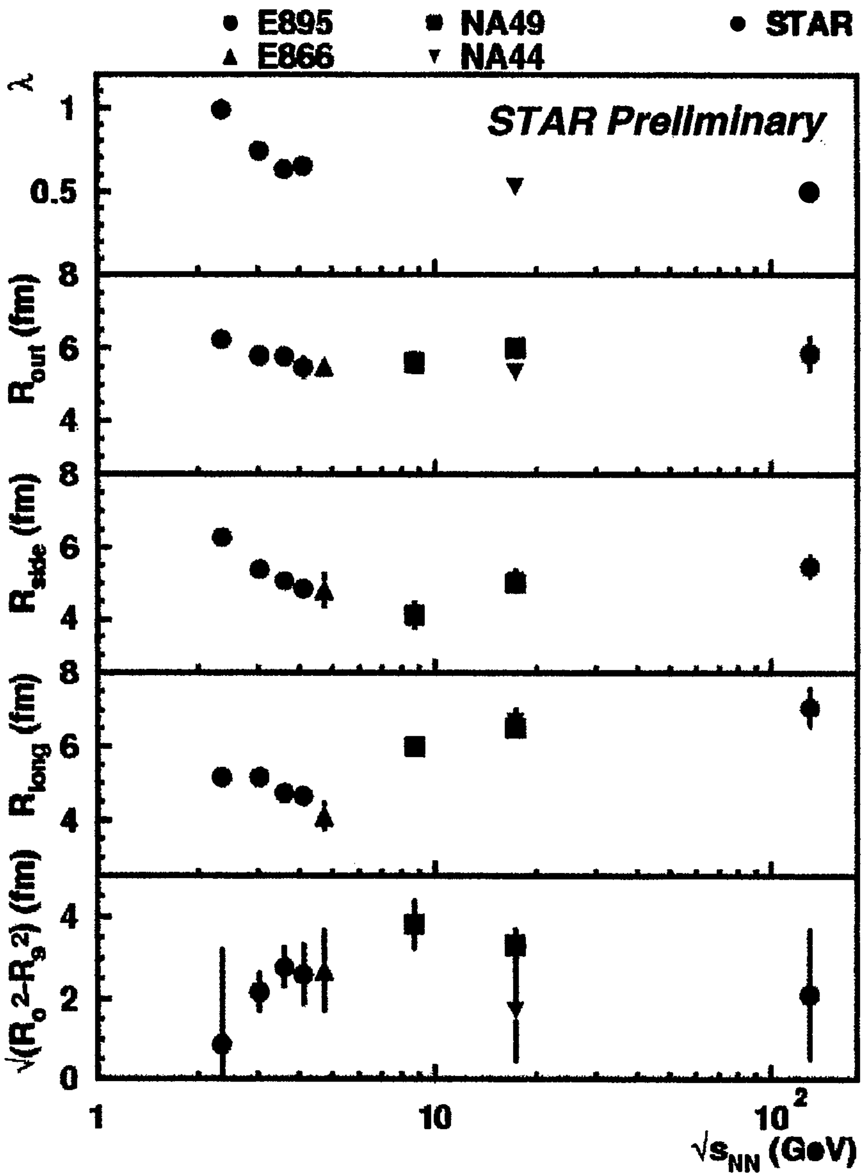


Fig. 23

Compilation of world 3D $\pi\pi$-HBT parameters as a function of $\sqrt{s}$

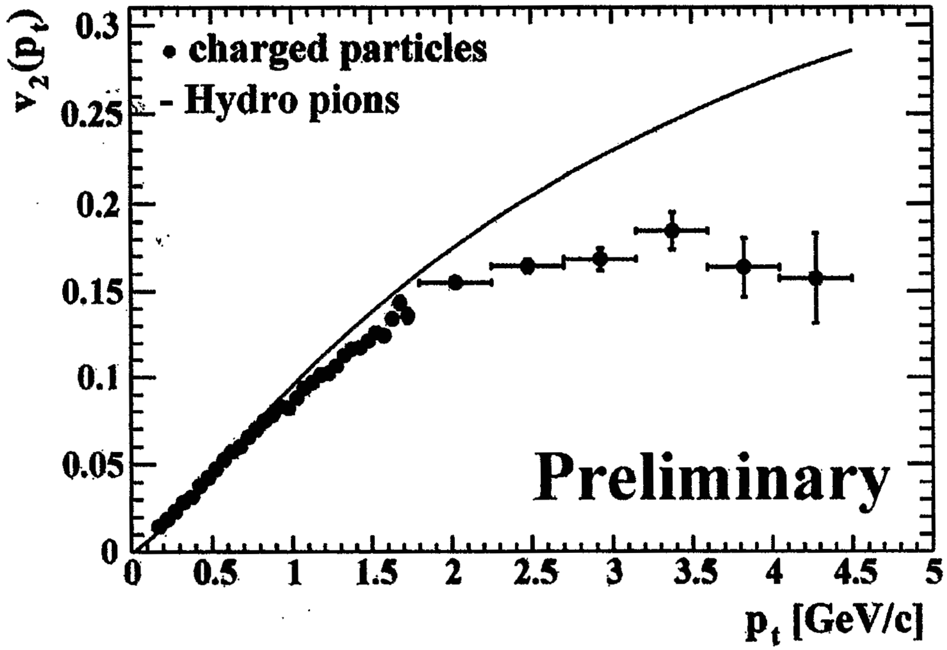
- **Surprising: source sizes roughly same as at AGS/SPS (< 10fm)**
- **radii increase with centrality (expected for R_{Out},R_{Side})**
- **Radii decrease with increasing k_T**
  - **flow**
- **$R_{Out}/R_{Side} \sim 1$**
  - **explosive source**
  - **short freeze-out**

STAR, submitted to PRL

Elliptic Flow - Centrality Dependence

v_2: 2^{nd} Fourier harmonic coefficient of azimuthal distribution of particles with respect to the reaction plane

STAR, PRL 86 (2001) 402



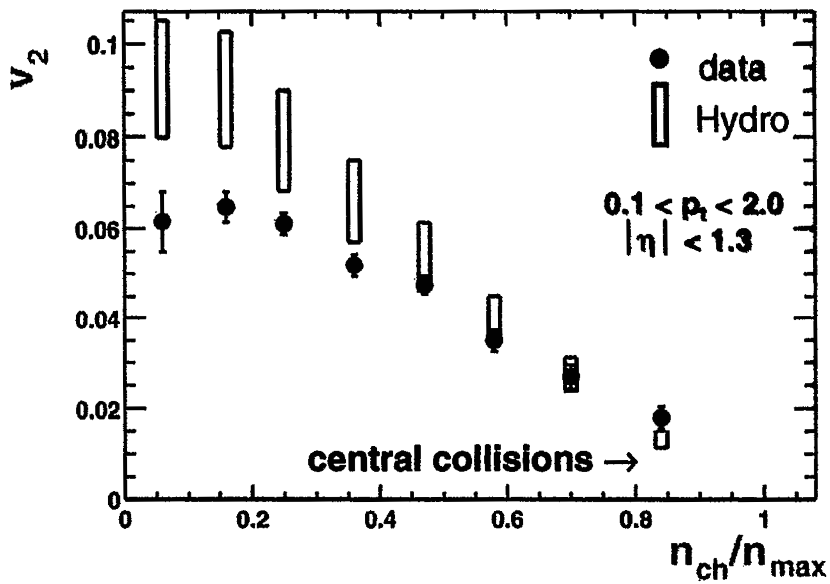


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Fig. 24

High p_T at RHIC

- **Measured in PHENIX for**
  - Charged hadrons
  - π^0's (with both PgGl and PbSc calorimeters)
- **Observe**
  - Peripheral collisions: Good agreement with scaled p-p reference
  - Central collisions: Clear deficit with respect to scaled reference

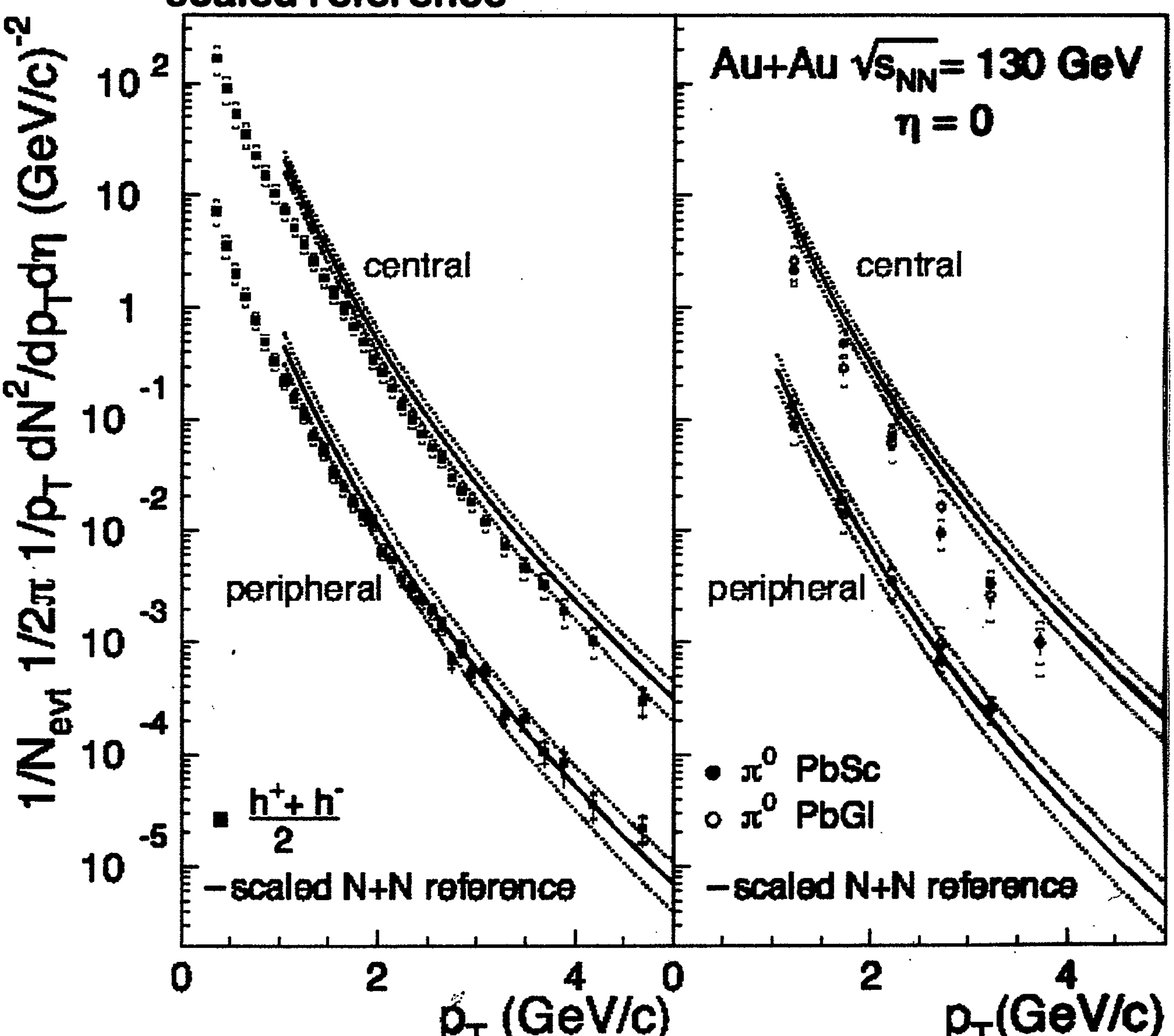

Fig. 25

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